



# A Comparison of Unit Commitment Techniques Dealing with Uncertainty

Daniel Kirschen, Hrvoje Pandzic, Yury Dvorkin,  
Yishen Wang, Ting Qiu

# Two-Stage Decision Process

---

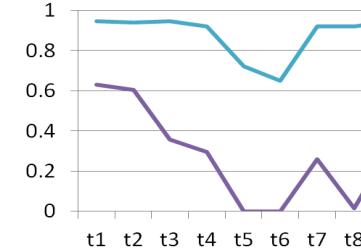
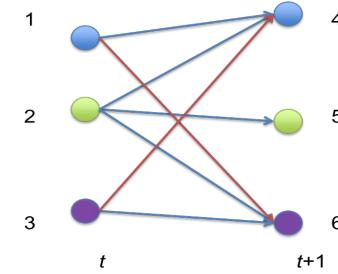
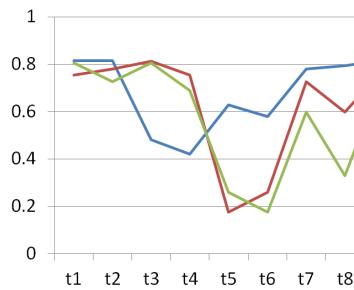
- *Day-ahead* decisions:
  - Binary commitment decision
  - Continuous dispatch decisions
  - Based on the expected net load
- *Corrective* decisions:
  - Differences between actual and expected net load
  - Binary commitment decisions are fixed for all but fast starting generators
  - Continuous decisions can be adjusted

# Scenarios vs. Range

---

- Scenarios-based approach:
  - Weighs the probability of each scenario and optimizes for the most likely scenarios
  - Accuracy depends on the number of scenarios
  - Computational burden increases with the number of scenarios
- Range-based approach:
  - Enforces the bounds and thus neglects the probability of individual scenarios
  - Sacrifice accuracy for computational efficiency

# Stochastic UC methods

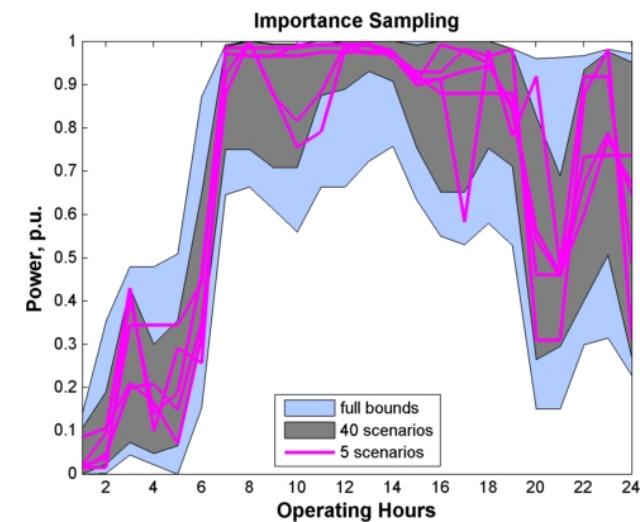
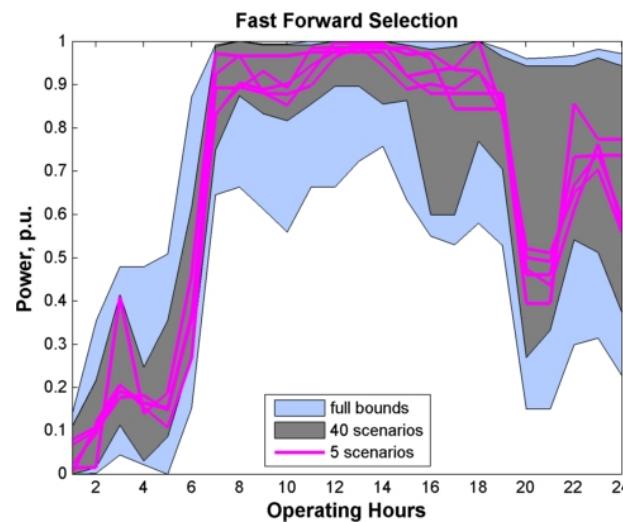


Approach	Scenario-based	Interval-based	Robust
Uncertainty	Scenarios	Uncertainty range	Uncertainty range
Objective (Minimize)	The expected cost of the scenarios considered	The cost of the most likely wind forecast	The highest cost among all realizations
Robustness	Increases with the number of scenarios	High	High
Computation time	Higher	Lower	Depends on the worst scenario searching process

- The interval-based and robust-based approaches are a form of scenario reduction technique

# Scenario reduction techniques (SRT)

- Different scenario-reduction techniques produce different scenarios



# Scenario reduction techniques (SRT)

ACTUAL OPERATING COST (IN  $10^3\$$ ) OF THE SCENARIO-BASED UC

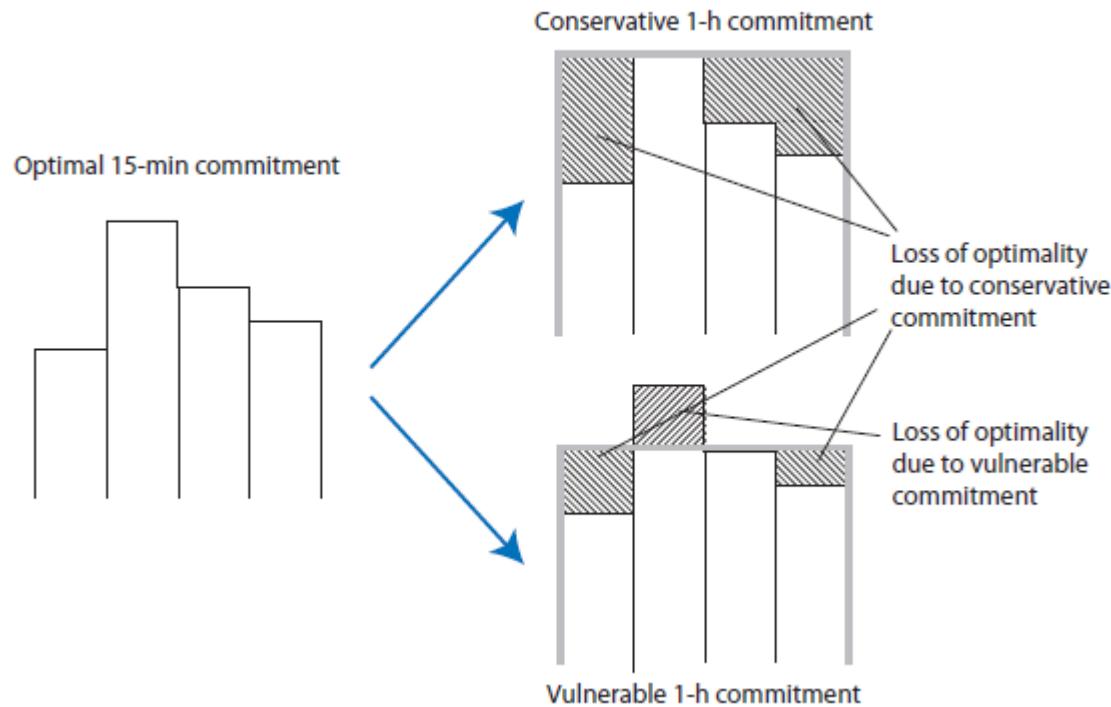
		SCHEMES			
		Positively Correlated Wind and Load			
Scenarios	Parameter	FSS	BSR	k-means	IS
5	$E(AOC)$	593.0*	593.1	593.1	596.2
	$\sigma(AOC)$	17.7	17.7	16.2	16.1
	$E(\Delta)$	26.3	24.3	26.1	28.5
	$E(SC)40$	21.3	21.1	21.3	22.9
	$\sigma(SC)$	0.719	0.728	0.715	0.708
10	$E(AOC)$	590.4*	591.0	590.8	592.2
	$\sigma(AOC)$	17.3	17.3	17.3	15.8
	$E(\Delta)$	19.8	19.8	20.3	17
	$E(SC)40$	19.5	21.1	21.3	10.8
	$\sigma(SC)$	0.188	0.186	0.182	0.204
20	$E(AOC)$	590.5*	591.5	590.9	593.1
	$\sigma(AOC)$	16.1	16.0	15.7	15.7
	$E(\Delta)$	17.5	19.1	13.4	15.3
	$E(SC)40$	21.4	21.1	23.1	23.1
	$\sigma(SC)$	0.167	0.157	0.193	0.150
40	$E(AOC)$	593.3*	593.5	594.2	596.7
	$\sigma(AOC)$	15.7	15.8	15.5	15.7
	$E(\Delta)$	17.3	16.9	16.1	18.5
	$E(SC)40$	22.9	22.9	22.8	22.8
	$\sigma(SC)$	0.155	0.191	0.138	0.138

- FFS consistently results in the least cost solution for any number of scenarios chosen
- The least-cost number of scenarios is 10, which is relatively tractable
- Different SRT result in different CPU times

COMPUTATION TIME (SEC) FOR THE SCENARIO-BASED UC SCHEDULES

Positively Correlated Wind and Load				
Scenarios	FSS	BSR	k-means	IS
5	53.8	54.1	58.9	59.0
10	168.0	156.6	290.8	271.6
20	864.3	1027	1143	1943
40	2208	3516	4097	4801

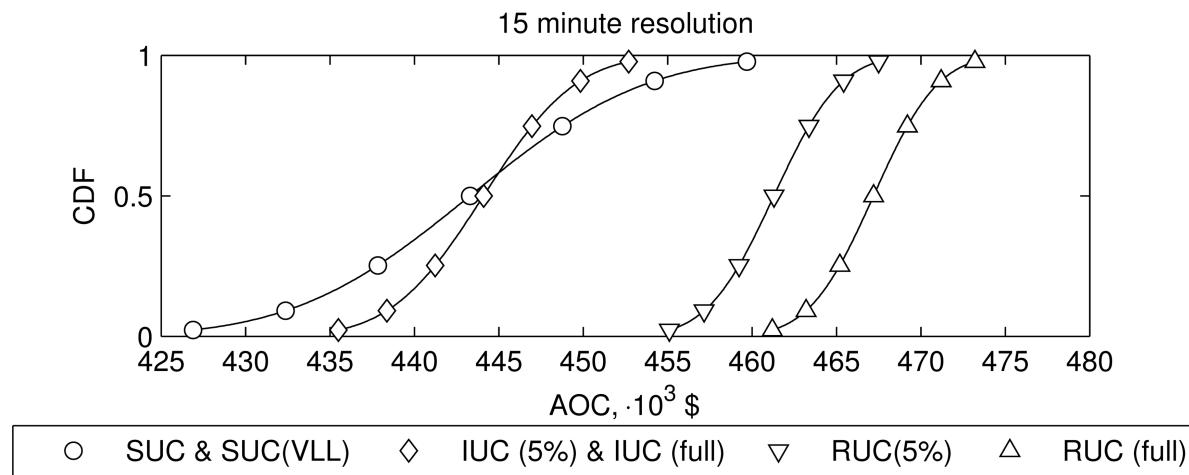
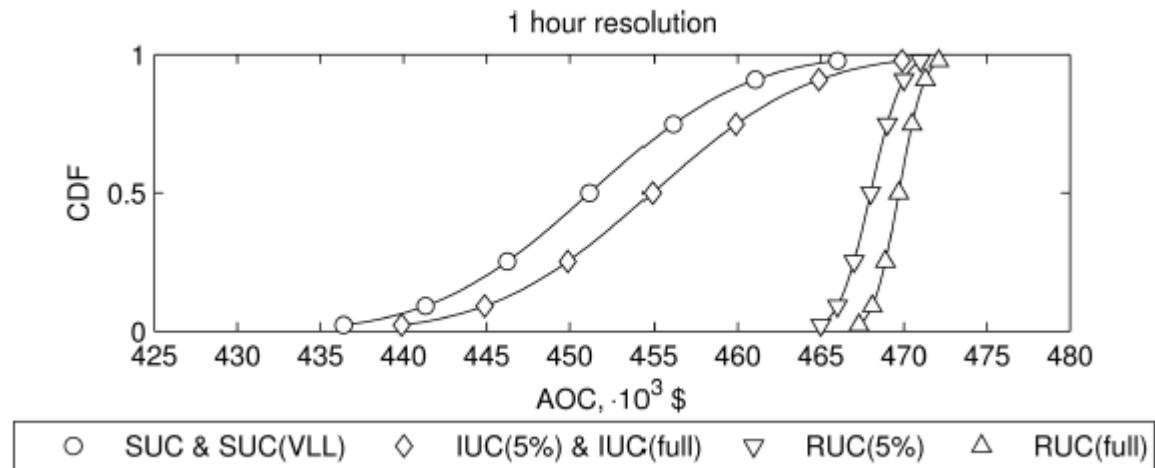
# The impact of time resolution



- Sub-hourly resolution can lower the cost at the expense of a higher computing time

# The impact of time resolution: Cost

---



# The impact of time resolution: Time

---

DAY-AHEAD COST (IN  $\cdot 10^3 \$$ ) AND COMPUTATION TIME (SEC)

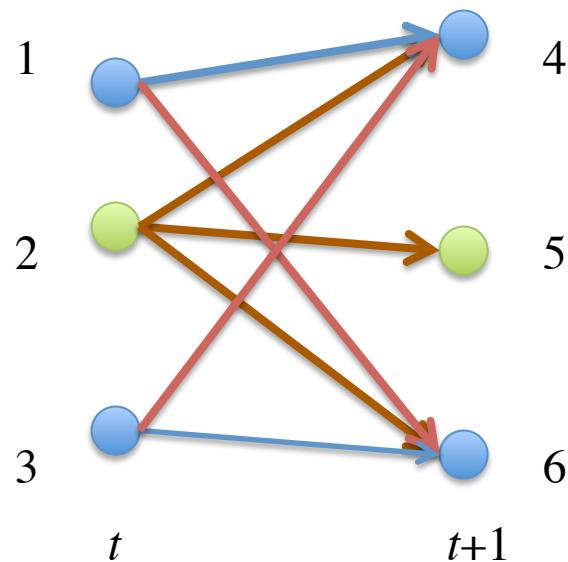
Approach	Day-Ahead Cost		Computation Time	
	1 hour	15 minute	1 hour	15 minute
Stochastic	419.7	446.5	38min:31s	8h:25min:27s
Stochastic ( <i>VLL</i> )	418.8	–	2h:4min:33s	–
Interval (5% bound)	415.5	443.1	32s	1min:8s
Interval (full)	418.8	443.1	31s	1min:38s
Robust (5% bound)	471.2	506.7	1min:12s	2min:5s
Robust (full)	499.8	529.7	1min:18s	2min:11s

- Large increase for scenario-based approaches
- Modest increase for the interval and robust approaches

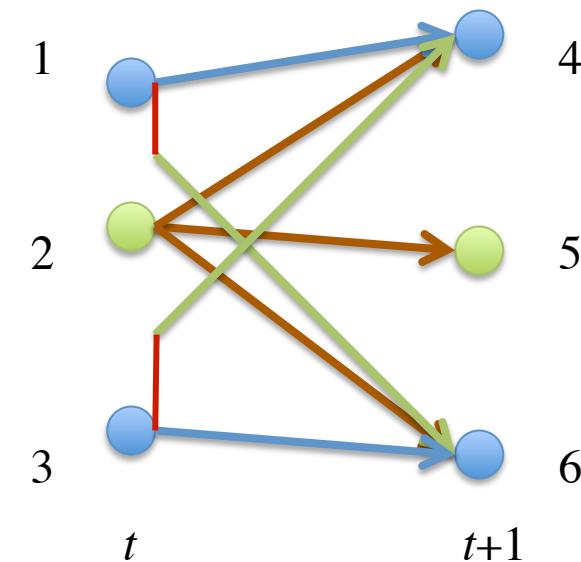
# Improved interval UC

---

Interval UC



“Improved” Interval UC  
reduced ramping requirements

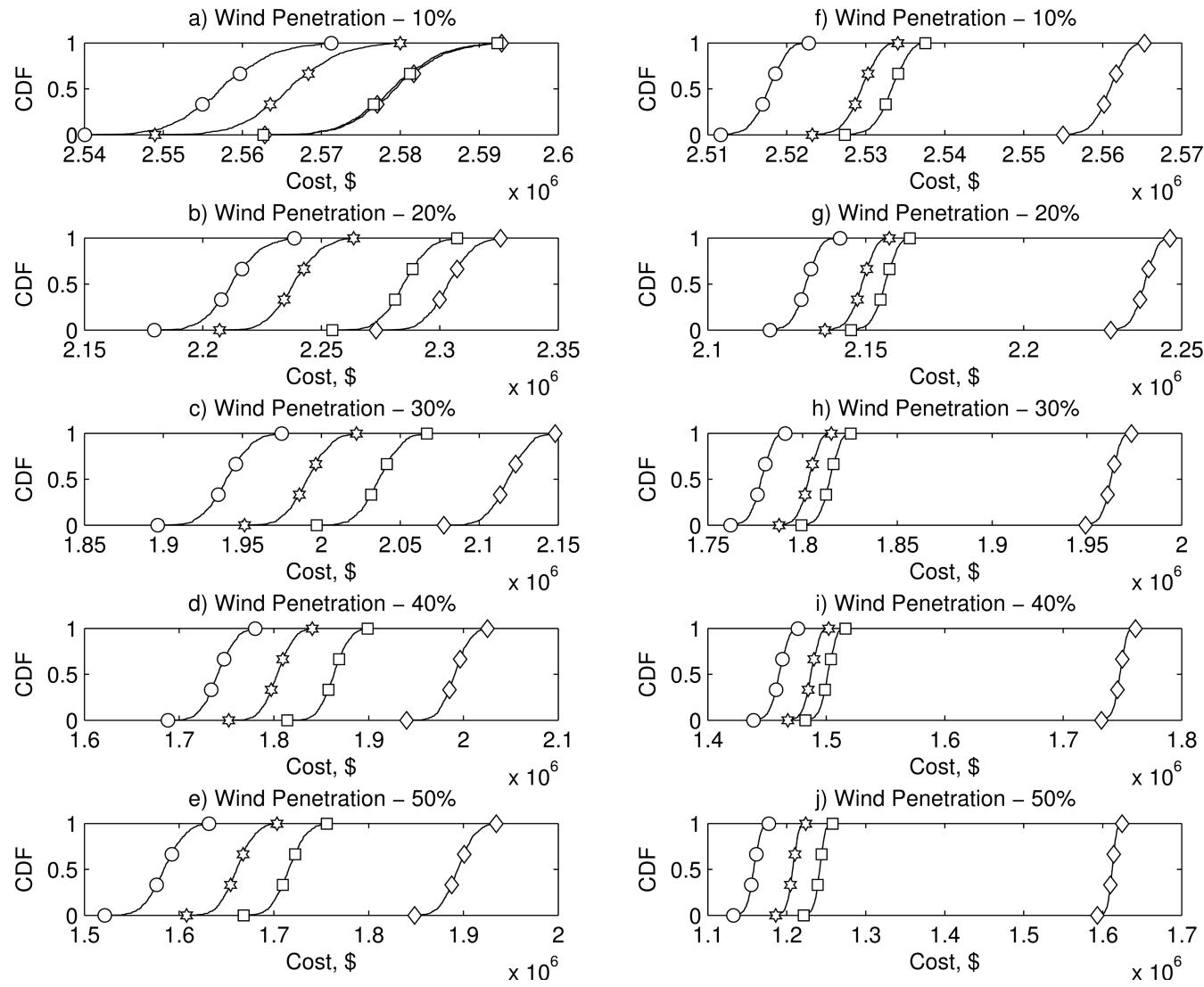


# Comparative Testing

---

- IEEE RTS 96: 73 buses, 96 generators
- Added 19 wind farms
- Favorable and unfavorable wind profiles
- Two sets of generator data (more and less flexible)
- 10-50% wind penetration levels
- Comparison between:
  - Stochastic (10 scenarios)
  - Robust
  - Interval
  - Improved interval

# Test case results – flexible generators

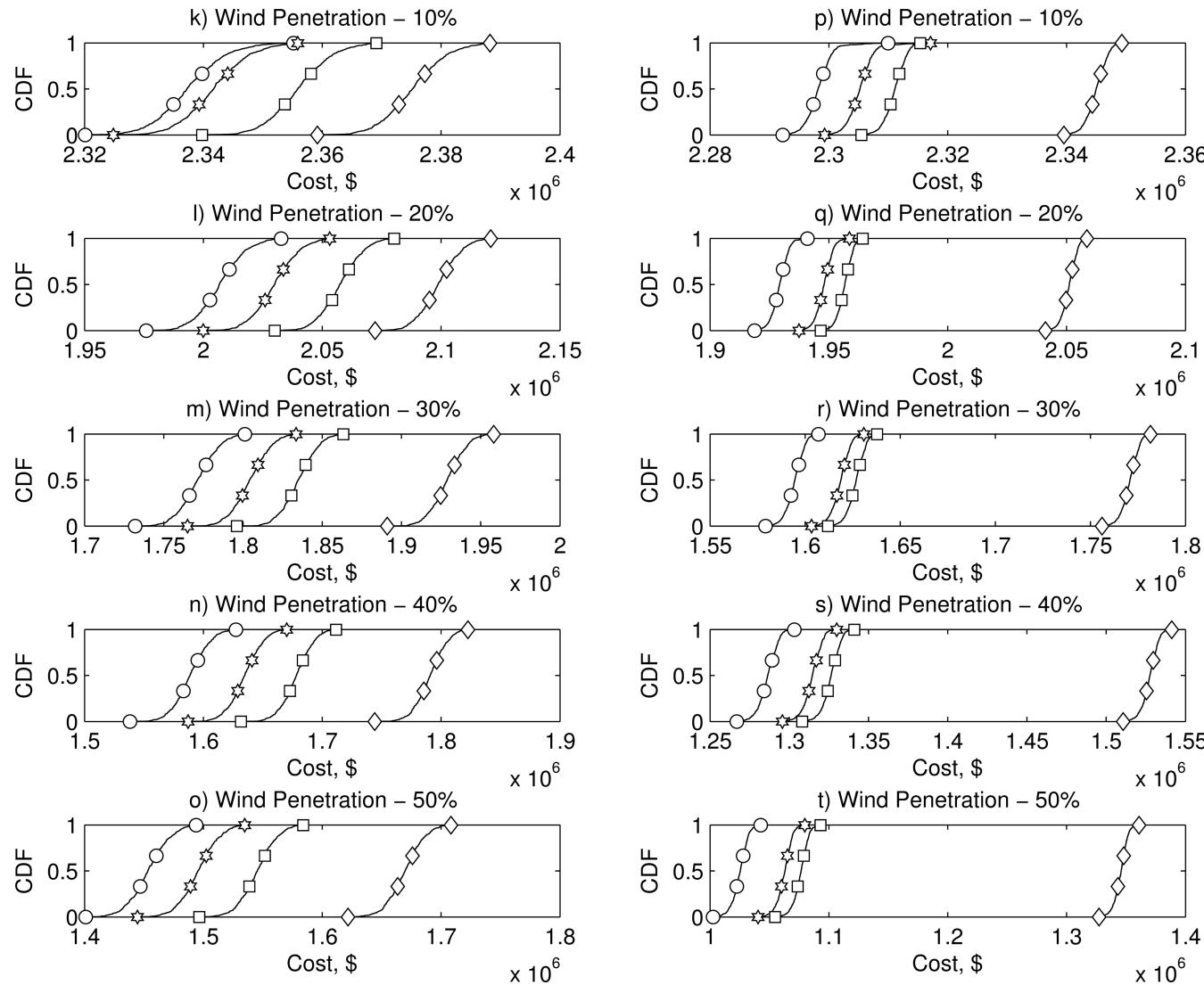


Unfavorable wind profile

○ SUC   ☆ IIUC   ◇ IUC   □ RUC

Favorable wind profile

# Test case results – inflexible generators

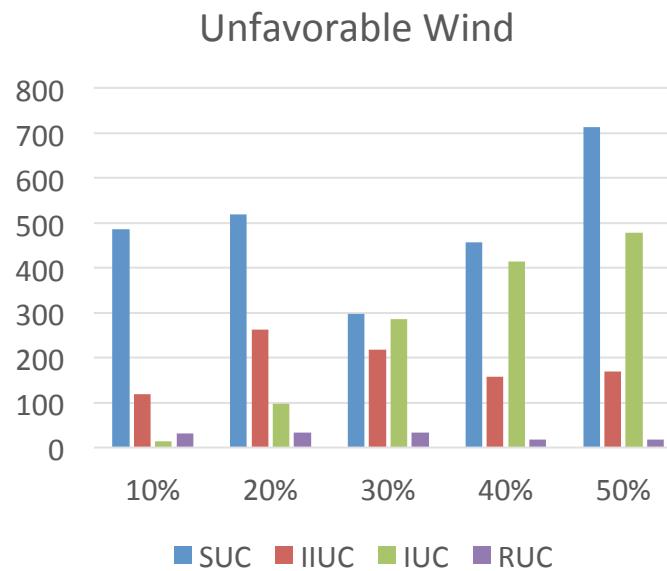
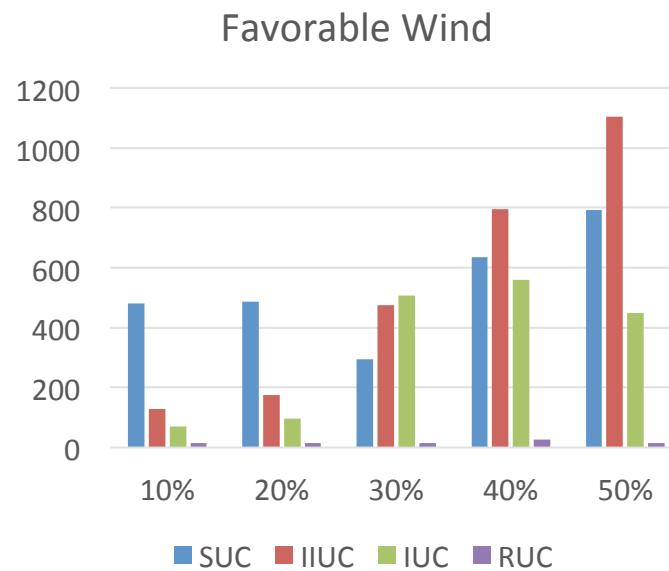


Unfavorable wind profile

Favorable wind profile

# Computation time - flexible generators

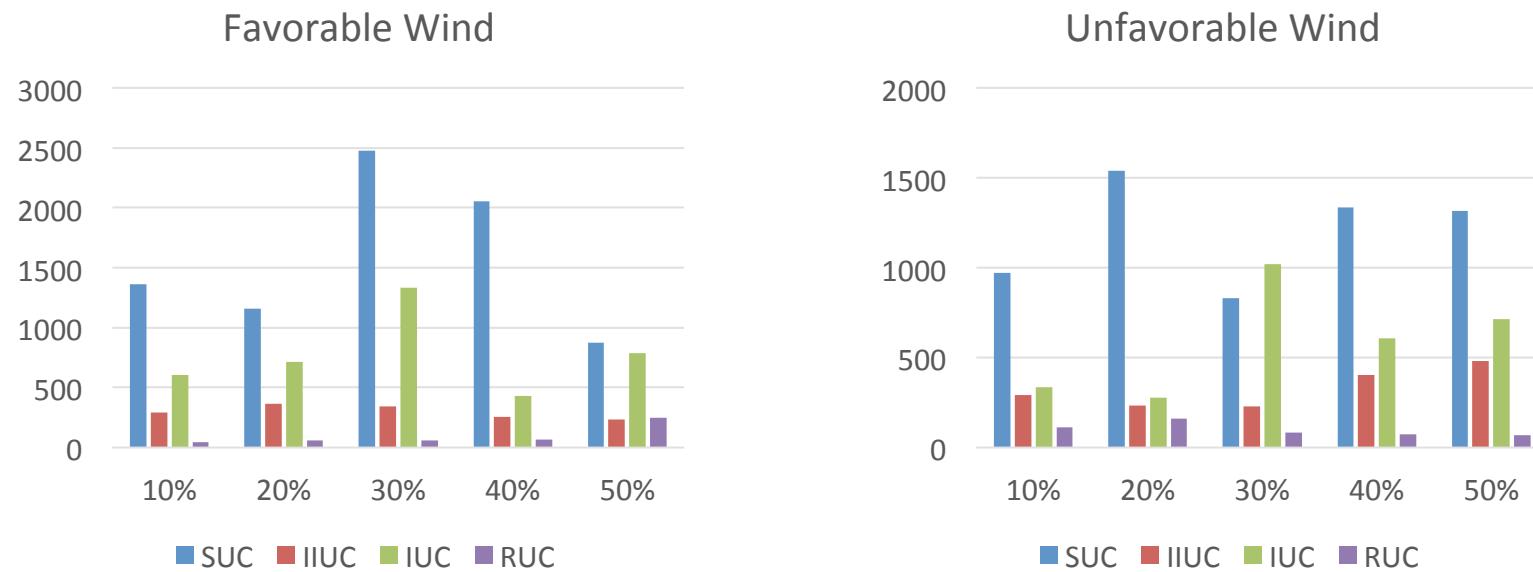
---



Results based on a 1% duality gap

# Computation time - flexible generators

---



Results based on a 1% duality gap

# Conclusions

---

- In terms of cost:
  - Scenario-based < Improved Interval < Robust < Interval
- In terms of computational burden:
  - Robust almost always the most efficient
  - Improved Interval and Interval are comparable
  - In 80% of all cases, SUC is most time consuming

# References

---

- Y. Dvorkin, Y. Wang, H. Pandzic, D. S. Kirschen, "Comparison of Scenario Reduction Techniques for the Stochastic Unit Commitment," to appear in Proc. of 2014 *IEEE Power and Energy Society General Meeting*, Washington DC, 2014.
- H. Pandzic, Y. Dvorkin, Y. Wang, T. Qiu, D. S. Kirschen, "Effect of Time Resolution on Unit Commitment Decisions in Systems with High Wind Penetration," to appear in Proc. of 2014 *IEEE Power and Energy Society General Meeting*, Washington DC, 2014.
- Y. V. Dvorkin, H. Pandzic, M. A. Ortega-Vazquez, D. S. Kirschen, "A Hybrid Stochastic/Interval Approach to Transmission-Constrained Unit Commitment with Uncertainty," under review .
- H. Pandzic, Y. Dvorkin, Y. Wang, T. Qiu, D. S. Kirschen, "Improved Interval Unit Commitment with Uncertainty," under review.